# Implication of a Signal from Brain Optical Topography

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## Summary

The implication of the signal obtained by the Optical Topography* is still unclear. We made simultaneous measurement of a functional MRI and the Optical Topography by using hand gripping task. The results indicate that there are statistically significant correlation between total-Hb and oxy-Hb signal and functional MRI signal, but deoxy-Hb signal did not show any correlation with functional MRI signal. This discrepancy can be explained by assuming that the signal of Optical Topograph mainly detecting a small vessel such as capillary hemoglobin of the brain but functional MRI signal is not restricted to such small vessels. Using this model, a signal from Optical Topography can be easily understood. First, an increase of total-Hb or oxy-Hb may reflect an increase of capillary beds. Second, a decrease of deoxy-Hb is fully explained by an increase of blood flow velocity at capillary level.

Key Words: Optical Topography, oxy-Hb, deoxy-Hb, cerebral blood flow, f-MRI

## 1. Introduction

Application fields of the Optical Topography* system developed by Hitachi Medical Corporation has been expanded and it has been recognized that the system can be used for measurement of cerebral function, however, the implication of the signals obtained by Optical Topography is still unclear.

In this study, simultaneous measurements of Optical Topography and functional MRI (f-MRI) were made to find the implication of the signals obtained by Optical Topography.

Also, making an assumption about the vessels detected by near-infrared measurement on the basis of the findings, simulation of cerebral blood flow was performed to study the implication of the signals obtained by the Optical Topography system.

## 2. Simultaneous measurement of Optical Topography and f-MRI

### 2.1 Optical Topography system

The Optical Topography system model ETG-100 manufactured by Hitachi Medical Corporation was used in this study (Fig. 1). This system incorporating the semiconductor laser emitting near-infrared rays (780nm and 830nm) is provided with 5 light source fibers and 4 detector fibers, 9 fibers in total for one hemisphere that are fixed onto the head with the special holder (Fig. 2). Using these 18 fibers for the both hemispheres cerebral measurement at multiple points are performed, thereby optical absorption at multiple point in brain is measured and oxyhemoglobin (oxy-Hb), deoxyhemoglobin (deoxy-Hb) and total-Hb in brain are calculated and visualized in image.

Time resolution is 0.1s. For details of the system, refer to the reference.[1]

Fig. 1
Optical Topography system ETG-100.

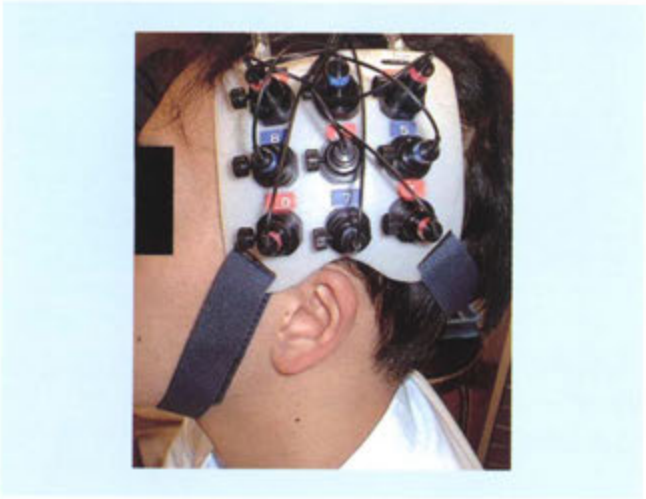

Fig. 2
Probes mounted on head; 9 glass fibers are attached to left side scalp.

2.2 Functional MRI

Functional MRI (f-MRI) was performed by Philips ACS-NT 1.5T MRI system.

Echo-Planar (EP) technique was used as pulse sequence. Three axial slices were acquired in parallel with OM-line. Scan time was 50ms, and three images were averaged to produce one image. An image was acquired every 6s and 50 images were acquired through 5 minutes task.

2.3 Simultaneous measurements of Optical Topography and f-MRI

For simultaneous measurement, fibers of 10m in length were used as fiber for the light source and the detector. The preliminary experiments showed that any change in signal was not found even by using these fibers. The patient connected with the fibers for Optical Topography was placed in the birdcage type coil for f-MRI (Fig. 3), the head was immobilized with the polyurethane foam pad and placed in the MRI gantry for measurement.

To visualize the position for optical measurement, the fibers were disconnected from the holder after measurement, and capsules containing garlic extract oil were placed into fiber holders to acquire T1-weighted image (Fig. 4).

This method provided information on the fiber positions of Optical Topography (measurement positions), and the measurement channel for the region nearest the MRI-activated region was selected.

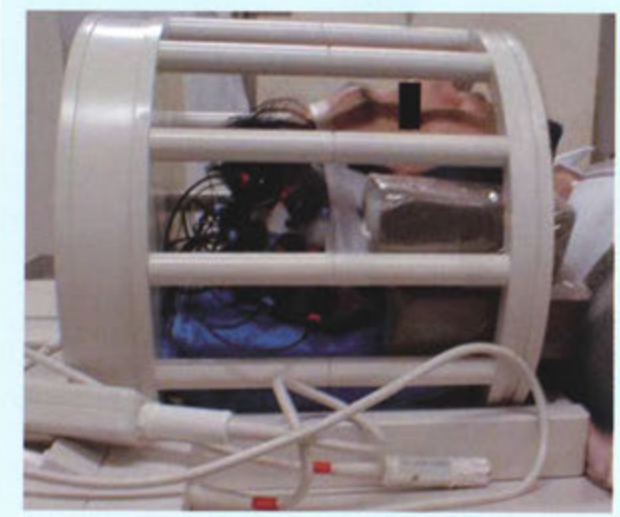

Fig. 3
Fibers mounted inside MRI coil for Optical Topography.

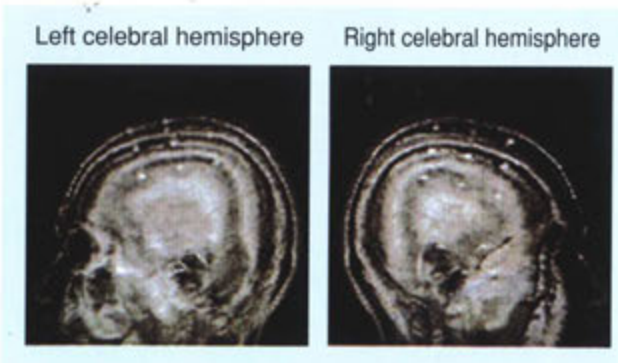


Fig. 4
Markers for fiber positions using garlic extract oil.
(T1-weighted image)

### 2.4 Objects and methods

Three healthy volunteers (right-handed male, average 35-year-old) were studied as object. Hand gripping task was given to both hands, and after one min. rest, the second kinetic load was given. The required measurement time was 5 min.

## 3. Results

The f-MRI results are shown in Fig. 5. Increase in signal intensity in all the 3 slices is shown in the primary motor and sensory areas as both hands movements. An example of the results detected by Optical Topography is shown in Fig. 6. The results of the obtained correlation between f-MRI signal and Optical Topography signal is also shown in Fig. 7 (right hemisphere) and Fig. 8 (left hemisphere). Statistically significant correlations were shown between f-MRI signal and oxy-Hb or total Hb in both the left and right hemispheres, and any statistical significance was not found in correlation between f-MRI signal and deoxy-Hb.

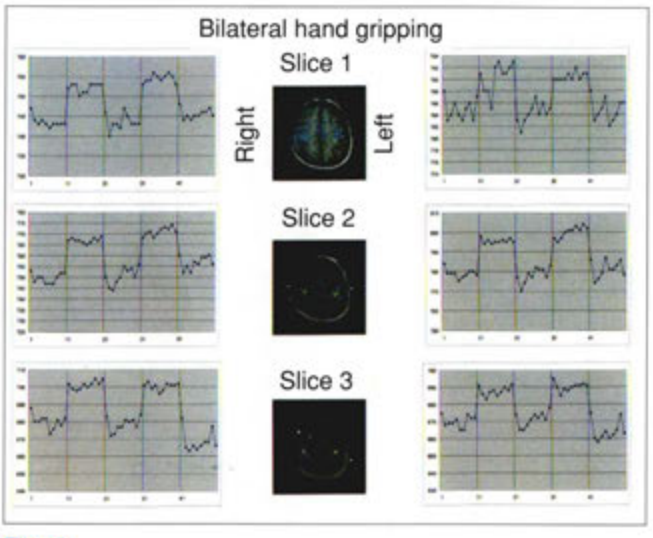


Fig. 5
An example of f-MRI Signals.

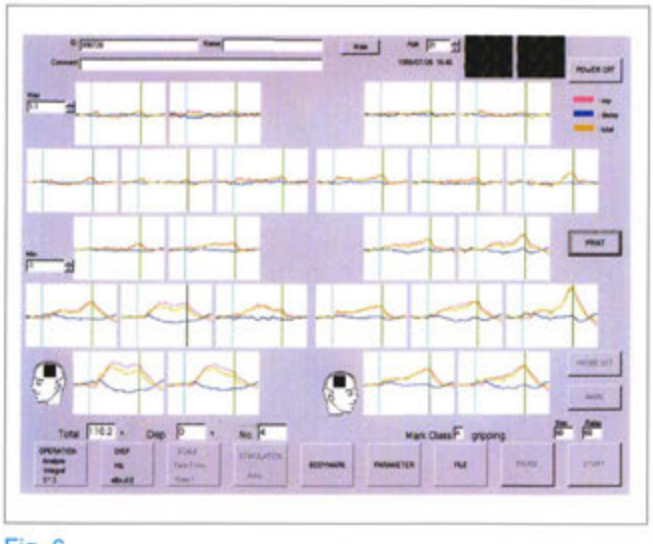

Fig. 6
An example of Optical Topography measurement.

## 4. Discussion

### 4.1 Correlation between total-Hb and oxy-Hb

It has been proved that Optical Topography is a useful modality to acquire information on hemoglobin in brain, however, there are still some unclear points about implication of the acquired signals.

Signal intensity of f-MRI is considered to be generated by BOLD (Blood Oxygen Level Dependent) effect and in-flow effect.[2)3)] The BOLD effect is explained as follows. Because cerebral blood flow increases as increase of neural-activity and especially increase in regional cerebral blood flow (rCBF) becomes greater than that of metabolism, regional total-Hb and oxy-Hb increase and paramagnetic deoxy-Hb decreases relatively. Consequently, $T_2^*$ is prolonged, thereby scanning with gradient echo sequence or echo-planar sequence sensitive to $T_2^*$ enhances signal intensity from those regions. The f-MRI signals are derived from these neural activity related signals.

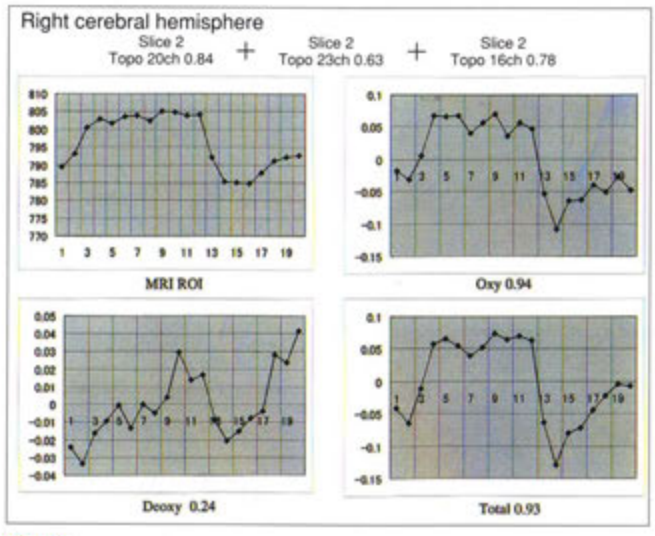


Fig. 7
Correlation between f-MRI signals and Optical Topography signals in right cerebral hemisphere.

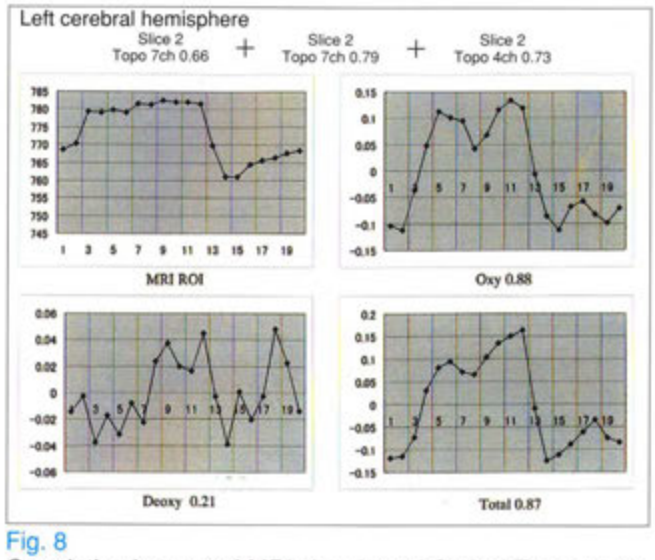


Fig. 8
Correlation between f-MRI signals and Optical Topography signals in left cerebral hemisphere.

On the other hand, in-flow effect is the phenomenon that water with unsaturated spins in the vessels outside the imaging slice flows into the imaging slice as increase of rCBF, resulting in enhancing the signal intensity in the regions where rCBF increases. This also has an effect on f-MRI signal.

In general, f-MRI signal from high-field MRI system is affected mainly by BOLD effect, while signal from low-field MRI system is affected by in-flow effect. In in-flow effect, differentiation between oxy-Hb and deoxy-Hb cannot be significant. In the 1.5T system used for this study, it is difficult to determine which effect gives main contribution, but it may be safe to consider that both the effects make a contribution.

The fact that total-Hb signal and oxy-Hb signal by Optical Topography show a good correlation with f-MRI signal can be explained on the base of BOLD effect by the phenomenon that great increase in total-Hb and oxy-Hb decreases deoxy-Hb relatively and enhances f-MRI signal. However, the result that they have no correlation with deoxy-Hb at all must be studied from a different point of view.

In consideration of the phenomenon that total-Hb and oxy-Hb also increase by in-flow effect, they should show a good correlation with total-Hb and it can also be explained by this effect. Eventually, it can be said that the simultaneous measurement made this time cannot determine whether f-MRI signal is affected by BOLD effect or in-flow effect.

### 4.2 Reason why deoxy-Hb has no correlation with f-MRI signal

Studies on which region in cerebral tissues generates f-MRI signal have been made, and many of them report that both cerebral tissues and veins have effect on the signal generation, especially veins make greater contribution.

Even great veins in the superficial brain have an effect on the signal, and decrease in deoxy-Hb and increase in blood flow in that region contribute to enhancement of signal.[4,5] MRI signals are obtained by detecting magnetic resonance signals of water molecules in brain, and most of water in brain is considered affecting on the signals excluding water with extremely short relaxation time such as bound water even if there is any difference between relaxation times.

On the other hand, Optical Topography is affected by transmissivity of near-infrared light through cerebral tissues and its signal intensity depends on amount of transmitted light. That is, if light absorption is too great, detection is hardly possible.

Firbank, et al.[6] and Lie, et al.[7] report that the object to be measured in measurement of hemoglobin in brain by using near-infrared light is limited to small vessels in brain.

The apparent absorption coefficient $\langle \mu_a \rangle$ in the condition where vessel with high absorption coefficient exists in the tissues with low absorption coefficient is expressed by the following formula.

$$\langle \mu_a \rangle = \mu_a^t + f_v(\mu_a^b - \mu_a^t) exp[-r(\mu_a^b - \mu_a^t)] \quad (1)$$

where, $\langle \mu_a \rangle$ is apparent absorption coefficient,

$\mu_a^b$ is absorption coefficient of hemoglobin in vessel,

$\mu_a^t$ is absorption coefficient of other tissues as background,

$f_v$ is volume ratio of vessels to whole cerebral tissues and

$r$ is diameter of vessel.

Peripheral vessel is as small as about r = 0.006mm in radius through which a red blood cell of 7 $\mu$m can barely pass, and in consideration that a mean regional red blood cell volume in brain is 1.50%[8] and hematocrit is diluted by 72.4% as compared with that in great vessel,[9] because such dilution cannot be considered in any vessels other than peripheral vessels, $f_v$ of peripheral vessels can be assumed to be 0.02.

On the other hand, as $\mu_a^b - \mu_a^t$ is assumed to be 3-5 $cm^{-1}$ and $\mu_a^t$ is assumed to be 0.06$cm^{-1}$,[7] referring to these values, the relation between diameter of blood vessel and absorption coefficient is shown in Fig. 9.

From these results, the detected signals are considered to be nearly at the level of peripheral vessel.

Fig. 10 shows a typical example of Optical Topogra-

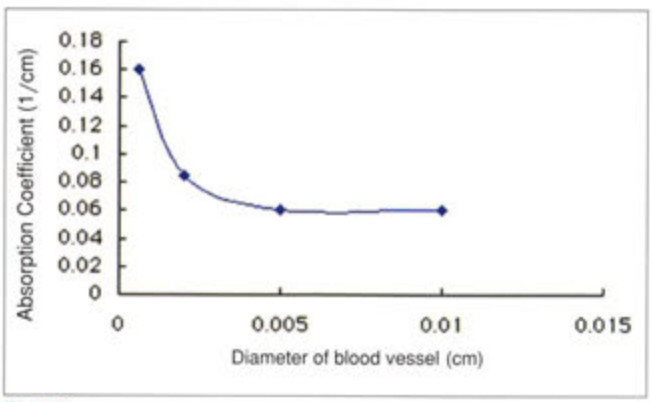


Fig. 9
Relation between diameter of blood vessel and absorption coefficient.

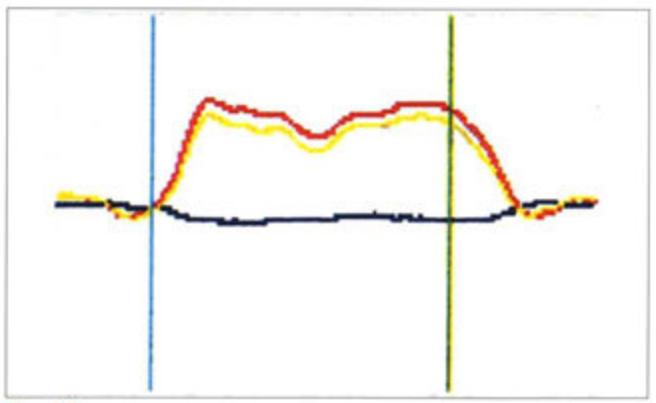

Fig. 10
Typical example of Optical Topography signal in primary motor and sensory areas under bilateral hand gripping motion by normal volunteer.

phy signals in the cerebral primary motor and sensory areas under hand gripping motion of healthy subject. As kinetic load is given, the phenomenon that total-Hb(yellow) and oxy-Hb(red) usually increase and deoxy-Hb(blue) decreases can be observed. Increase in total-Hb and oxy-Hb can be explained by the reason that rCBF increases due to activation of cerebral neural tissues caused by motor task. However, decrease in deoxy-Hb cannot be explained only by this reason.

Fig.11 shows our view on cerebral blood flow. As rCBF is a volume of blood flowing per unit time, it can be considered that its volume is virtually a product of area S and flow velocity v. Therefore, increase in cerebral blood flow CBF is caused by increase in S and/or v. Increase in S concretely means increase in peripheral blood vessel bed (capillary bed), and only this phenomena means that increase in deoxy-Hb due to increase in energy metabolism caused by motor task is stayed in small vessels and increase in deoxy-Hb is seen under motor task as shown in the left image in Fig. 12.

On the other hand, increase in v of CBF allows oxy-Hb(arterial blood : red) to be fed deep into peripheral vessels, thus causing deoxy-Hb to be distributed more into vein region. Now, by assuming that near-infrared light detects mainly peripheral vessel level (capillary) as previously described, increase in flow velocity flushes out deoxy-Hb(venous blood : blue) to larger venous systems where deoxy-Hb cannot be detected, and as shown in the right image in Fig. 12, deoxy-Hb apparently decreases.

## 5. Conclusion

As a conclusion of the above discussion, the signals detectable by Optical Topography:

(1) are mainly acquired from small vessels such as peripheral blood vessels (capillary) and do not include signals from larger vessels.

(2) Increase in total-Hb and oxy-Hb means mainly increase in S, that is, increase in cerebral peripheral blood vessel bed.

(3) Decrease in deoxy-Hb reflects increase in flow velocity v due to increase in CBF.

By interpreting the results as above, the conclusion can be understood more easily.

Naturally, the signals from greater vessels in the superficial brain are also included, its contribution can be considered to be less.

From this model, the reason why there is no correlation between deoxy-Hb and f-MRI can be understood. In other words, it can be considered that f-MRI signals contain information on larger vessels including venous system, while Optical Topography detects mainly hemoglobin in smaller vessels such as capillary.

We outlined the implication of the signals to be obtained by Optical Topography in this report and hope it can be helpful to understand more about Optical Topography.

※ Optical Topography is a registered trade name of Hitachi, Ltd.

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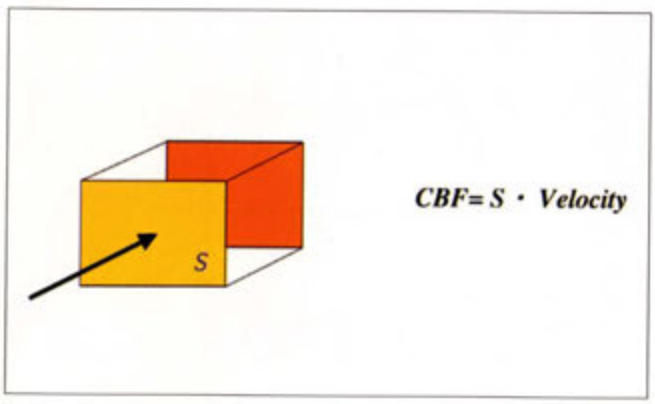


Fig. 11
Conception of cerebral blood flow.

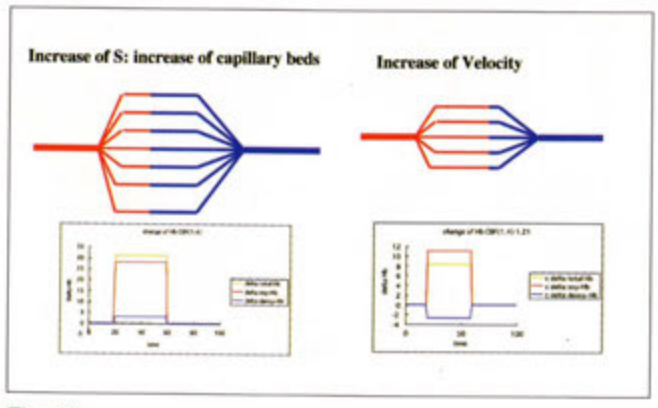


Fig. 12
Change in S and change in velocity.

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